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(54) **HEATER BUNDLE FOR ADAPTIVE CONTROL**

HEIZUNGSBÜNDEL FÜR ANPASSUNGSFÄHIGE STEUERUNG

FAISCEAU DE CHAUFFAGE POUR COMMANDE ADAPTABLE

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Description

FIELD

[0001] The present disclosure relates to electric heaters, and more particularly to heaters for heating a fluid flow such as heat exchangers.

BACKGROUND

[0002] Heater systems according to the preamble of independent claim 1 have been disclosed for example in US 3 340 382.

[0003] A fluid heater may be in the form of a cartridge heater, which has a rod configuration to heat fluid that flows along or past an exterior surface of the cartridge heater. The cartridge heater may be disposed inside a heat exchanger for heating the fluid flowing through the heat exchanger. If the cartridge heater is not properly sealed, moisture and fluid may enter the cartridge heater to contaminate the insulation material that electrically insulates a resistive heating element from the metal sheath of the cartridge heater, resulting in dielectric breakdown and consequently heater failure. The moisture can also cause short circuiting between power conductors and the outer metal sheath. The failure of the cartridge heater may cause costly downtime of the apparatus that uses the cartridge heater.

SUMMARY

[0004] According to a first aspect, the present invention relates to a heater system according to claim 1.

[0005] According to a second aspect, the present invention relates to an apparatus for heating fluid according to claim 32.

[0006] According to a third aspect, the present invention relates to a method of controlling a heating system according to claim 17.

DRAWINGS

[0007] In order that the disclosure may be well understood, there will now be described various forms thereof, given by way of example, reference being made to the accompanying drawings, in which:

FIG. 1 is a perspective view of a heater bundle constructed in accordance with the teachings of the present disclosure;

FIG. 2 is a perspective view of a heater assembly of the heater bundle of FIG. 1;

FIG. 3 is a perspective view of a variant of a heater assembly of the heater bundle of FIG. 1;

FIG. 4 is a perspective view of the heater assembly of FIG. 3, wherein the outer sheath of the heater assembly is removed for clarity;

FIG. 5 is a perspective view of a core body of the

heater assembly of FIG. 3;

FIG. 6 is a perspective view of a heat exchanger including the heater bundle of FIG. 1, wherein the heater bundle is partially disassembled from the heat exchanger to expose the heater bundle for illustration purposes; and

FIG. 7 is a block diagram of a method of operating a heater system including a heater bundle constructed in accordance with the teachings of the present disclosure.

DETAILED DESCRIPTION

[0008] Referring to FIG. 1, a heater system constructed in accordance with the teachings of the present disclosure is generally indicated by reference 10. The heater system 10 includes a heater bundle 12 and a power supply device 14 electrically connected to the heater bundle 12. The power supply device 14 includes a controller 15 for controlling power supply to the heater bundle 12. A "heater bundle", as used in the present disclosure, refers to a heater apparatus including two or more physically distinct heating devices that can be independently controlled. Therefore, when one of the heating devices in the heater bundle fails or degrades, the remaining heating devices in the heater bundle 12 can continue to operate.

[0009] In one form, the heater bundle 12 includes a mounting flange 16 and a plurality of heater assemblies 18 secured to the mounting flange 16. The mounting flange 16 includes a plurality of apertures 20 through which the heater assemblies 18 extend. Although the heater assemblies 18 are arranged to be parallel in this form, it should be understood that alternate positions/arrangements of the heater assemblies 18 are within the scope of the present disclosure.

[0010] As further shown, the mounting flange 16 includes a plurality of mounting holes 22. By using screws or bolts (not shown) through the mounting holes 22, the mounting flange 16 may be assembled to a wall of a vessel or a pipe (not shown) that carries a fluid to be heated. At least a portion of the heater assemblies 18 are immersed in the fluid inside the vessel or pipe to heat the fluid in this form of the present disclosure.

[0011] Referring to FIG. 2, which illustrates an embodiment that is not in accordance with the present invention, the heater assemblies 18 according to one form may be in the form of a cartridge heater 30. The cartridge heater 30 is a tube-shaped heater that generally includes a core body 32, a resistive heating wire 34 wrapped around the core body 32, a metal sheath 36 enclosing the core body 32 and the resistive heating wire 34 therein, and an insulating material 38 filling in the space in the metal sheath 36 to electrically insulate the resistive heating wire 34 from the metal sheath 36 and to thermally conduct the heat from the resistive heating wire 34 to the metal sheath 36. The core body 32 may be made of ceramic. The insulation material 38 may be compacted Magnesium Oxide (MgO). A plurality of power conductors 42 extend

through the core body 32 along a longitudinal direction and are electrically connected to the resistive heating wires 34. The power conductors 42 also extend through an end piece 44 that seals the outer sheath 36. The power conductors 42 are connected to the external power supply device 14 (shown in FIG. 1) to supply power from the external power supply device 14 to the resistive heating wire 32. While FIG. 2 shows only two power conductors 42 extending through the end piece 44, more than two power conductors 42 can extend through the end piece 44. The power conductors 42 may be in the form of conductive pins. Various constructions and further structural and electrical details of cartridge heaters are set forth in greater detail in U.S. Patent Nos. 2,831,951 and 3,970,822, which are commonly assigned with the present application.

[0012] Alternatively, multiple resistive heating wires 34 and multiple pairs of power conductors 42 may be used to form multiple heating circuits that can be independently controlled to enhance reliability of the cartridge heater 30. Therefore, when one of the resistive heating wires 34 fails, the remaining resistive wires 34 may continue to generate heat without causing the entire cartridge heater 30 to fail and without causing costly machine downtime.

[0013] Referring to FIGS. 3 to 5, the heater assemblies 50 may be in the form of a cartridge heater having a configuration similar to that of FIG. 2 except for the number of core bodies and number of power conductors used. More specifically, the heater assemblies 50 each include a plurality of heater units 52, and an outer metal sheath 54 enclosing the plurality of heater units 52 therein, along with a plurality of power conductors 56. An insulating material (not shown in FIGS. 3 to 5) is provided between the plurality of heating units 52 and the outer metal sheath 54 to electrically insulate the heater units 52 from the outer metal sheath 54. The plurality of heater units 52 each include a core body 58 and a resistive heating element 60 surrounding the core body 58. The resistive heating element 60 of each heater unit 52 may define one or more heating circuits to define one or more heating zones 62.

[0014] In the present form, each heater unit 52 defines one heating zone 62 and the plurality of heater units 52 in each heater assembly 50 are aligned along a longitudinal direction X. Therefore, each heater assembly 50 defines a plurality of heating zones 62 aligned along the longitudinal direction X. The core body 58 of each heater unit 52 defines a plurality of through holes/apertures 64 to allow power conductors 56 to extend therethrough. The resistive heating elements 60 of the heater units 52 are connected to the power conductors 56, which, in turn, are connected to an external power supply device 14. The power conductors 56 supply the power from the power supply device 14 to the plurality of heater units 50. By properly connecting the power conductors 56 to the resistive heating elements 60, the resistive heating elements 60 of the plurality of heating units 52 can be inde-

pendently controlled by the controller 15 of the power supply device 14. As such, failure of one resistive heating element 60 for a particular heating zone 62 will not affect the proper functioning of the remaining resistive heating elements 60 for the remaining heating zones 62. Further, the heater units 52 and the heater assemblies 50 may be interchangeable for ease of repair or assembly.

[0015] In the present form, six power conductors 56 are used for each heater assembly 50 to supply power to five independent electrical heating circuits on the five heater units 52. Alternatively, six power conductors 56 may be connected to the resistive heating elements 60 in a way to define three fully independent circuits on the five heater units 52. It is possible to have any number of power conductors 56 to form any number of independently controlled heating circuits and independently controlled heating zones 62. For example, seven power conductors 56 may be used to provide six heating zones 62. Eight power conductors 56 may be used to provide seven heating zones 62.

[0016] The power conductors 56 may include a plurality of power supply and power return conductors, a plurality of power return conductors and a single power supply conductor, or a plurality of power supply conductors and a single power return conductor. If the number of heater zones is n , the number of power supply and return conductors is $n + 1$.

[0017] Alternatively, a higher number of electrically distinct heating zones 62 may be created through multiplexing, polarity sensitive switching and other circuit topologies by the controller 15 of the external power supply device 14. Use of multiplexing or various arrangements of thermal arrays to increase the number of heating zones within the cartridge heater 50 for a given number of power conductors (e.g. a cartridge heater with six power conductors for 15 or 30 zones.) is disclosed in U.S. Patent Nos. 9,123,755, 9,123,756, 9,177,840, 9,196,513, and their related applications, which are commonly assigned with the present application.

[0018] With this structure, each heater assembly 50 includes a plurality of heating zones 62 that can be independently controlled to vary the power output or heat distribution along the length of the heater assembly 50. The heater bundle 12 includes a plurality of such heater assemblies 50. Therefore, the heater bundle 12 provides a plurality of heating zones 62 and a tailored heat distribution for heating the fluid that flows through the heater bundle 12 to be adapted for specific applications. The power supply device 14 can be configured to modulate power to each of the independently controlled heating zones 62.

[0019] For example, a heating assembly 50 may define an "m" heating zones, and the heater bundle may include "k" heating assemblies 50. Therefore, the heater bundle 12 may define $m \times k$ heating zones. The plurality of heating zones 62 in the heater bundle 12 can be individually and dynamically controlled in response to heating conditions and/or heating requirements, including but not limited to,

the life and the reliability of the individual heater units 52, the sizes and costs of the heater units 52, local heater flux, characteristics and operation of the heater units 52, and the entire power output.

[0020] Each circuit is individually controlled at a desired temperature or a desired power level so that the distribution of temperature and/or power adapts to variations in system parameters (e.g. manufacturing variation/tolerances, changing environmental conditions, changing inlet flow conditions such as inlet temperature, inlet temperature distribution, flow velocity, velocity distribution, fluid composition, fluid heat capacity, etc.). More specifically, the heater units 52 may not generate the same heat output when operated under the same power level due to manufacturing variations as well as varied degrees of heater degradation over time. The heater units 52 may be independently controlled to adjust the heat output according to a desired heat distribution. The individual manufacturing tolerances of components of the heater system and assembly tolerances of the heater system are increased as a function of the modulated power of the power supply, or in other words, because of the high fidelity of heater control, manufacturing tolerance of individual components need not be as tight/narrow.

[0021] The heater units 52 may each include a temperature sensor (not shown) for measuring the temperature of the heater units 52. When a hot spot in the heater units 52 is detected, the power supply device 14 may reduce or turn off the power to the particular heater unit 52 on which the hot spot is detected to avoid overheating or failure of the particular heater unit 52. The power supply device 14 may modulate the power to the heater units 52 adjacent to the disabled heater unit 52 to compensate for the reduced heat output from the particular heater unit 52.

[0022] The power supply device 14 may include multi-zone algorithms to turn off or turn down the power level delivered to any particular zone, and to increase the power to the heating zones adjacent to the particular heating zone that is disabled and has a reduced heat output. By carefully modulating the power to each heating zone, the overall reliability of the system can be improved. By detecting the hot spot and controlling the power supply accordingly, the heater system 10 has improved safety.

[0023] The heater bundle 12 with the multiple independently controlled heating zones 62 can accomplish improved heating. For example, some circuits on the heater units 52 may be operated at a nominal (or "typical") duty cycle of less than 100% (or at an average power level that is a fraction of the power that would be produced by the heater with line voltage applied). The lower duty cycles allow for the use of resistive heating wires with a larger diameter, thereby improving reliability.

[0024] Normally, smaller zones would employ a finer wire size to achieve a given resistance. Variable power control allows a larger wire size to be used, and a lower resistance value can be accommodated, while protecting

the heater from overloading with a duty cycle limit tied to the power dissipation capacity of the heater.

[0025] The use of a scaling factor may be tied to the capacity of the heater units 52 or the heating zone 62.

5 The multiple heating zones 62 allow for more accurate determination and control of the heater bundle 12. The use of a specific scaling factor for a particular heating circuit/zone will allow for a more aggressive (i.e. higher) temperature (or power level) at almost all zones, which, 10 in turn, lead to a smaller, less costly design for the heater bundle 12. Such a scaling factor and method is disclosed in U.S. Patent No. 7,257,464, which is commonly assigned with the present application.

15 **[0026]** The sizes of the heating zones controlled by the individual circuits can be made equal or different to reduce the total number of zones needed to control the distribution of temperature or power to a desired accuracy.

20 **[0027]** Referring back to FIG. 1, the heater assemblies 18 are shown to be a single end heater, i.e., the conductive pin extends through only one longitudinal end of the heater assemblies 18. The heater assembly 18 may extend through the mounting flange 16 or a bulkhead (not shown) and sealed to the flange 16 or bulkhead. As such, 25 the heater assemblies 18 can be individually removed and replaced without removing the mounting flange 16 from the vessel or tube.

30 **[0028]** Alternatively, the heater assembly 18 may be a "double ended" heater. In a double-ended heater, the metal sheath are bent into a hairpin shape and the power conductors pass through both longitudinal ends of the metal sheath so that both longitudinal ends of the metal sheath pass through and are sealed to the flange or bulkhead. In this structure, the flange or the bulkhead need 35 to be removed from the housing or the vessel before the individual heater assembly 18 can be replaced.

40 **[0029]** Referring to FIG. 6, a heater bundle 12 is incorporated in a heat exchanger 70. The heat exchanger 70 includes a sealed housing 72 defining an internal chamber (not shown), a heater bundle 12 disposed within the internal chamber of the housing 72. The sealed housing 72 includes a fluid inlet 76 and a fluid outlet 78 through which fluid is directed into and out of the internal chamber of the sealed housing 72. The fluid is heated by the heater 45 bundle 12 disposed in the sealed housing 72. The heater bundle 12 may be arranged for either cross-flow or for flow parallel to their length.

50 **[0030]** The heater bundle 12 is connected to an external power supply device 14 which may include a means to modulate power, such as a switching means or a variable transformer, to modulate the power supplied to an individual zone. The power modulation may be performed as a function of time or based on detected temperature of each heating zone.

55 **[0031]** The resistive heating wire may also function as a sensor using the resistance of the resistive wire to measure the temperature of the resistive wire and using the same power conductors to send temperature meas-

urement information to the power supply device 14. A means of sensing temperature for each zone would allow the control of temperature along the length of each heater assembly 18 in the heater bundle 12 (down to the resolution of the individual zone). Therefore, the additional temperature sensing circuits and sensing means can be dispensed with, thereby reducing the manufacturing costs. Direct measurement of the heater circuit temperature is a distinct advantage when trying to maximize heat flux in a given circuit while maintaining a desired reliability level for the system because it eliminates or minimizes many of the measurement errors associated with using a separate sensor. The heating element temperature is the characteristic that has the strongest influence on heater reliability. Using a resistive element to function as both a heater and a sensor is disclosed in U.S. Patent No. 7,196,295, which is commonly assigned with the present application.

[0032] Alternatively, the power conductors 56 may be made of dissimilar metals such that the power conductors 56 of dissimilar metals may create a thermocouple for measuring the temperature of the resistive heating elements. For example, at least one set of a power supply and a power return conductor may include different materials such that a junction is formed between the different materials and a resistive heating element of a heater unit and is used to determine temperature of one or more zones. Use of "integrated" and "highly thermally coupled" sensing, such as using different metals for the heater leads to generation of a thermocouple-like signal. The use of the integrated and coupled power conductors for temperature measurement is disclosed in U.S. Published Application No. 2016/0353521, which is commonly assigned with the present application.

[0033] The controller 15 for modulating the electrical power delivered to each zone may be a closed-loop automatic control system. The closed-loop automatic control system 15 receives the temperature feedback from each zone and automatically and dynamically controls the delivery of power to each zone, thereby automatically and dynamically controlling the power distribution and temperature along the length of each heater assembly 18 in the heater bundle 12 without continuous or frequent human monitoring and adjustment.

[0034] The heater units 52 as disclosed herein may also be calibrated using a variety of methods including but not limited to energizing and sampling each heater unit 52 to calculate its resistance. The calculated resistance can then be compared to a calibrated resistance to determine a resistance ratio, or a value to then determine actual heater unit temperatures. Exemplary methods are disclosed in U.S. Patent Nos. 5,280,422 and 5,552,998, which are commonly assigned with the present application.

[0035] One form of calibration includes operating the heater system 10 in at least one mode of operation, controlling the heater system 10 to generate a desired temperature for at least one of the independently controlled

heating zones 62, collecting and recording data for the at least one independently controlled heating zones 62 for the mode of operation, then accessing the recorded data to determine operating specifications for a heating system having a reduced number of independently controlled heating zones, and then using the heating system with the reduced number of independently controlled heating zones. The data may include, by way of example, power levels and/or temperature information, among other operational data from the heater system 10 having its data collected and recorded.

[0036] In a variation of the present disclosure, the heater system may include a single heater assembly 18, rather than a plurality of heater assemblies in a bundle 12. The single heater assembly 18 would comprise a plurality of heater units 52, each heater unit 52 defining at least one independently controlled heating zone. Similarly, power conductors 56 are electrically connected to each of the independently controlled heating zones 62 in each of the heater units 62, and the power supply device is configured to modulate power to each of the independently controlled heater zones 62 of the heater units through the power conductors 56.

[0037] Referring to FIG. 7, a method 100 of controlling a heater system includes providing a heater bundle comprising a plurality of heater assemblies in step 102. Each heater assembly includes a plurality of heater units. Each heater unit defines at least one independently controlled heating circuit (and consequently heating zone). The power to each of the heater units is supplied through power conductors electrically connected to each of the independently controlled heating zones in each of the heater units in step 104. The temperature within each of the zones is detected in step 106. The temperature may be determined using a change in resistance of a resistive heating element of at least one of the heater units. The zone temperature may be initially determined by measuring the zone resistance (or, by measurement of circuit voltage, if appropriate materials are used).

[0038] The temperature values may be digitalized. The signals may be communicated to a microprocessor. The measured (detected) temperature values may be compared to a target (desired) temperature for each zone in step 108. The power supplied to each of the heater units may be modulated based on the measured temperature to achieve the target temperatures in step 110.

[0039] Optionally, the method may further include using a scaling factor to adjust the modulating power. The scaling factor may be a function of a heating capacity of each heating zone. The controller 15 may include an algorithm, potentially including a scaling factor and/or a mathematical model of the dynamic behavior of the system (including knowledge of the update time of the system), to determine the amount of power to be provided (via duty cycle, phase angle firing, voltage modulation or similar techniques) to each zone until the next update. The desired power may be converted to a signal, which is sent to a switch or other power modulating device for

controlling power output to the individual heating zones.

[0040] In the present form, when at least one heating zone is turned off due to an anomalous condition, the remaining zones continue to provide a desired wattage without failure. Power is modulated to a functional heating zone to provide a desired wattage when an anomalous condition is detected in at least one heating zone. When at least one heating zone is turned off based on the determined temperature, the remaining zones continue to provide a desired wattage. The power is modulated to each of the heating zones as a function of at least one of received signals, a model, and as a function of time.

[0041] For safety or process control reasons, typical heaters are generally operated to be below a maximum allowable temperature in order to prevent a particular location of the heater from exceeding a given temperature due to unwanted chemical or physical reactions at the particular location, such as combustion/fire/oxidation, coking boiling etc.). Therefore, this is normally accommodated by a conservative heater design (e.g., large heaters with low power density and much of their surface area loaded with a much lower heat flux than might otherwise be possible).

[0042] However, with the heater bundle of the present disclosure, it is possible to measure and limit the temperature of any location within the heater down to a resolution on the order of the size of the individual heating zones. A hot spot large enough to influence the temperature of an individual circuit can be detected.

[0043] Since the temperature of the individual heating zones can be automatically adjusted and consequently limited, the dynamic and automatic limitation of temperature in each zone will maintain this zone and all other zones to be operating at an optimum power/heat flux level without fear of exceeding the desired temperature limit in any zone. This brings an advantage in high-limit temperature measurement accuracy over the current practice of clamping a separate thermocouple to the sheath of one of the elements in a bundle. The reduced margin and the ability to modulate the power to individual zones can be selectively applied to the heating zones, selectively and individually, rather than applied to an entire heater assembly, thereby reducing the risk of exceeding a predetermined temperature limit.

[0044] The characteristics of the cartridge heater may vary with time. This time varying characteristic would otherwise require that the cartridge heater be designed for a single selected (worse-case) flow regime and therefore that the cartridge heater would operate at a sub-optimum state for other states of flow.

[0045] However, with dynamic control of the power distribution over the entire bundle down to a resolution of the core size due to the multiple heating units provided in the heater assembly, an optimized power distribution for various states of flow can be achieved, as opposed to only one power distribution corresponding to only one flow state in the typical cartridge heater. Therefore, the

heater bundle of the present application allows for an increase in the total heat flux for all other states of flow.

[0046] Further, variable power control can increase heater design flexibility. The voltage can be de-coupled from resistance (to a great degree) in heater design and the heaters may be designed with the maximum wire diameter that can be fitted into the heater. It allows for increased capacity for power dissipation for a given heater size and level of reliability (or life of the heater) and allows for the size of the bundle to be decreased for a given overall power level. Power in this arrangement can be modulated by a variable duty cycle that is a part of the variable wattage controllers currently available or under development. The heater bundle can be protected by a programmable (or pre-programmed if desired) limit to the duty cycle for a given zone to prevent "overloading" the heater bundle.

Claims

1. A heater system (10) comprising a heater bundle (12), the heater bundle (12) comprising: a plurality of heater assemblies (18), each heater assembly (18) comprising a plurality of heater units (52), each heater unit (52) defining at least one independently controlled heating zone (62); a plurality of power conductors (56) electrically connected to each of the at least one independently controlled heating zone (62) in each of the heater units (52); and means for detecting temperature within each of the independently controlled heating zones (62); and a power supply device (14);

characterized in that the power supply device (14) includes a controller (15) configured to modulate power to each of the independently controlled heating zones (62) of the heater units (52) through the power conductors (56) based on detected temperature within each of the independently controlled heating zones (62) to provide a desired wattage along a length of each of the heater assemblies (18).

2. The heater system (10) according to Claim 1 further comprising a closed-loop automatic control system (15) configured to control power from the power supply device based on the detected temperatures within at least one of the independently controlled heating zones (62).
3. The heater system (10) according to Claim 1 wherein the power conductors (56) comprise one of: a plurality of power supply and power return conductors, a plurality of power return conductors and a single power supply conductor, or a plurality of power supply conductors and a single power return conductor.
4. The heater system (10) according to Claim 1, wherein the heater units (52) of the heater assemblies (18)

have the same structure such that the heater units (52) of the heater assemblies (18) are interchangeable.

5. The heater system (10) according to Claim 1, wherein at least one set of a power supply and a power return conductor comprise different materials such that a junction is formed between the different materials and a resistive heating element (34) of a heater unit (52) and is used to determine temperature of one or more of the independently controlled heating zones (62). 5
6. The heater system (10) according to Claim 1, wherein the number of the independently controlled heating zones (62) is n, and the number of power supply and return conductors is n + 1. 10
7. The heater system (10) according to Claim 1, wherein each heater assembly (18) defines an axis and the plurality of heater assemblies (18) are arranged such that their axes are arranged parallel to each other. 15
8. The heater system (10) according to Claim 1, wherein the plurality of heater units (52) each include a core body (32) and a resistive heating element (34) surrounding the core body (32). 20
9. The heater system (10) according to Claim 8, wherein the power conductors (56) extend through the core bodies (32) of the heater units (52). 25
10. The heater system (10) according to Claim 9, wherein the core bodies (32) of the heater assembly (18) are received within a metal sheath (36). 30
11. The heater system (10) according to Claim 8, wherein the core body (32) of each heater unit (52) defines a plurality of through holes (64). 35
12. The heater system (10) according to Claim 11, wherein the power conductors (56) extend in the plurality of through holes (64) of the core bodies (32). 40
13. The heater system (10) according to Claim 8, wherein the core bodies (32) of the heater units (52) are made of ceramic. 45
14. The heater system (10) according to Claim 8, wherein the core bodies (32) of each of the heater assemblies (18) are received within a metal sheath (36). 50
15. The heater system (10) according to Claim 14, further comprising an insulating material (38) disposed between the core bodies (32) and the metal sheath (36). 55
16. The heater system (10) according to Claim 1, wherein the number of the heater assemblies (18) is k, the number of the independently controlled heating zones (62) of each of the heater assemblies (18) is m, and a total number of the independently controlled heating zones (62) defined by the heater bundle (12) is $m \times k$.
17. A method of controlling a heating system (10) comprising: providing a plurality of heater assemblies (18), the heater assembly (18) comprising a plurality of heater units (52), each heater unit (52) defining at least one independently controlled heating zone (62); supplying power to each of the at least one independently controlled heating zone (62) in each of the heater units (52) through a plurality of power conductors (56), the power conductors (56) electrically connected to each of the at least one independently controlled heating zone (62) in each of the heater units (52); and detecting a temperature within each of the independently controlled heating zones (62);
characterized in that the method comprises modulating power supplied to each of the independently controlled heating zones (62) of the heater units (52) through the power conductors (56) based on detected temperature within each of the independently controlled heating zones (62) to provide a desired wattage along a length of the heater assembly (18).
18. The method according to Claim 17, further comprising comparing the detected temperatures to target temperatures and modulating the power supplied to achieve the target temperatures.
19. The method according to Claim 17, further comprising using a scaling factor to adjust the modulating power.
20. The method according to Claim 19, further comprising using the scaling factor as a function of a heating capacity of each heating zone (62).
21. The method according to Claim 17, further comprising turning off at least one of the independently controlled heating zones (62) based on the detected temperature while continuing to provide the desired wattage to remaining ones of the independently controlled heating zones (62).
22. The method according to Claim 17, wherein when the detected temperature in at least one of the heating zones (62) is deviated from a target temperature, power is modulated to the at least one heating zone (62) to achieve the target temperature.
23. The method according to Claim 17, wherein the detecting of the temperature includes determining the

temperature using a change in resistance of a resistive heating element (34) of at least one of the heater units (52).

24. The method according to Claim 23, further comprising turning off at least one of the independently controlled heating zones (62) based on the detected temperature, while continuing to provide the desired wattage to the remaining ones of the independently controlled heating zones (62).

25. The method according to Claim 17, wherein the power is modulated to each of the heating zones (62) as a function of at least one of received signals, a model, and as a function of time.

26. The method according to Claim 17, further comprising calibrating the heating system (10) according to the following steps:

operating the heater system (10) in at least one mode of operation;
controlling the heater system (10) to activate at least one of the plurality of independently controlled heating zones (62) to generate a desired temperature;
collecting and recording data for the at least one of the independently controlled heating zones (62) and the at least one mode of operation;
accessing the recorded data to determine operating specifications for the heater system (10) when the at least one of the plurality of independently controlled heating zones (62) is turned off; and
operating the heater system (10) with the at least one of the plurality of independently controlled heating zones (62) being turned off.

27. The method according to Claim 26, wherein the data is selected from the group consisting of power levels and temperature information.

28. The method according to Claim 17, wherein the plurality of heater units (52) are disposed along a longitudinal direction of the heater assembly (18) to define the plurality of independently controlled heating zones (62) along the longitudinal direction of the heater assembly (18).

29. The method according to Claim 17, further comprising providing a total of $m \times k$ independently controlled heating zones (62), wherein the number of the heater assemblies (18) is k , and the number of the independently controlled heating zones (62) of each of the heater assemblies (18) is m .

30. The method according to Claim 29, further comprising turning off at least one of the independently controlled heating zones (62) while continuing to supply power to remaining ones of the independently controlled heating zones (62) to provide the desired wattage along the length of the heater assembly (18).

31. The method according to Claim 17, wherein the plurality of independently controlled heating zones (62) are individually and dynamically controlled to achieve a predetermined power distribution across the heater system.

32. An apparatus for heating fluid comprising:

a sealed housing (72) defining an internal chamber and having a fluid inlet (76) and a fluid outlet (78); and
the heater system (10) according to Claim 1 disposed within the internal chamber of the housing (72),
wherein the heater bundle (12) is adapted to provide a predetermined heat distribution to a fluid within the housing (72).

Patentansprüche

1. Heizungssystem (10), umfassend ein Heizungsband (12), wobei das Heizungsband (12) umfasst: eine Vielzahl von Heizungsbaugruppen (18), wobei jede Heizungsbaugruppe (18) eine Vielzahl von Heizungseinheiten (52) umfasst, wobei jede Heizungseinheit (52) mindestens eine unabhängig gesteuerte Heizzone (62) definiert; eine Vielzahl von Stromleitern (56), die elektrisch mit jeder der mindestens einen unabhängig gesteuerten Heizzone (62) in jeder der Heizungseinheiten (52) verbunden ist; und Mittel zum Detektieren einer Temperatur innerhalb jeder der unabhängig gesteuerten Heizzonen (62); und eine Stromversorgungsvorrichtung (14);
dadurch gekennzeichnet, dass die Stromversorgungsvorrichtung (14) eine Steuerung (15) beinhaltet, die konfiguriert ist, um Strom zu jeder der unabhängig gesteuerten Heizzonen (62) der Heizungseinheiten (52) durch die Stromleiter (56) basierend auf der detektierten Temperatur innerhalb jeder der unabhängig gesteuerten Heizzonen (62) zu modulieren, um eine gewünschte Wattleistung entlang einer Länge jeder der Heizungsbaugruppen (18) bereitzustellen.
2. Heizungssystem (10) nach Anspruch 1, weiter ein Steuersystem (15) in einer geschlossenen Schleife umfassend, das konfiguriert ist, um Strom von der Stromversorgungsvorrichtung basierend auf den detektierten Temperaturen innerhalb mindestens einer der unabhängig gesteuerten Heizzonen (62) zu steuern.

3. Heizungssystem (10) nach Anspruch 1, wobei die Stromleiter (56) eines umfassen von: eine Vielzahl von Stromversorgungs- und Stromrückführleitungen, eine Vielzahl von Stromrückführleitungen und eine einzige Stromversorgungsleitung oder eine Vielzahl von Stromversorgungsleitungen und eine einzige Stromrückführleitung.
4. Heizungssystem (10) nach Anspruch 1, wobei die Heizungseinheiten (52) der Heizungsbaugruppen (18) dieselbe Struktur aufweisen, sodass die Heizungseinheiten (52) der Heizungsbaugruppen (18) untereinander austauschbar sind.
5. Heizungssystem (10) nach Anspruch 1, wobei mindestens ein Satz von einer Stromversorgungs- und einer Stromrückführleitung unterschiedliche Materialien umfassen, sodass eine Verbindung zwischen den verschiedenen Materialien und einem Heizwiderstandselement (34) einer Heizungseinheit (52) gebildet wird, und verwendet wird, um eine Temperatur von einer oder mehreren der unabhängig gesteuerten Heizzonen (62) zu bestimmen.
6. Heizungssystem (10) nach Anspruch 1, wobei die Anzahl der unabhängig gesteuerten Heizzonen (62) n ist, und die Anzahl der Stromversorgungs- und Rückführleiter $n+1$ ist.
7. Heizungssystem (10) nach Anspruch 1, wobei jede Heizungsbaugruppe (18) eine Achse definiert und die Vielzahl von Heizungsbaugruppen (18) derart angeordnet sind, dass ihre Achsen parallel zueinander angeordnet sind.
8. Heizungssystem (10) nach Anspruch 1, wobei die Vielzahl von Heizungseinheiten (52) jeweils einen Kernkörper (32) und ein Heizwiderstandselement (34) beinhalten, das den Kernkörper (32) umgibt.
9. Heizungssystem (10) nach Anspruch 8, wobei sich die Stromleiter (56) durch die Kernkörper (32) der Heizungseinheiten (52) hindurch erstrecken.
10. Heizungssystem (10) nach Anspruch 9, wobei die Kernkörper (32) der Heizungsbaugruppe (18) innerhalb einer Metallhülse (36) aufgenommen sind.
11. Heizungssystem (10) nach Anspruch 8, wobei der Kernkörper (32) jeder Heizungseinheit (52) eine Vielzahl von Durchgangslöchern (64) definiert.
12. Heizungssystem (10) nach Anspruch 11, wobei sich die Stromleiter (56) in der Vielzahl von Durchgangslöchern (64) der Kernkörper (32) erstrecken.
13. Heizungssystem (10) nach Anspruch 8, wobei die Kernkörper (32) der Heizungseinheiten (52) aus Keramik gefertigt sind.
14. Heizungssystem (10) nach Anspruch 8, wobei die Kernkörper (32) jeder der Heizungsbaugruppen (18) innerhalb einer Metallhülse (36) aufgenommen sind.
15. Heizungssystem (10) nach Anspruch 14, weiter ein Isoliermaterial (38) umfassend, das zwischen den Kernkörpern (32) und der Metallhülse (36) disponiert ist.
16. Heizungssystem (10) nach Anspruch 1, wobei die Anzahl der Heizungsbaugruppen (18) k ist die Anzahl der unabhängig gesteuerten Heizzonen (62) jeder der Heizungsbaugruppen (18) m ist und eine Gesamtanzahl der unabhängig gesteuerten Heizzonen (62), die durch das Heizungsbündel (12) definiert wird, $m \times k$ ist.
17. Verfahren zum Steuern eines Heizungssystems (10), umfassend: Bereitstellen einer Vielzahl von Heizungsbaugruppen (18), wobei die Heizungsbaugruppe (18) eine Vielzahl von Heizungseinheiten (52) umfasst, wobei jede Heizungseinheit (52) mindestens eine unabhängig gesteuerte Heizzone (62) definiert; Versorgen mit Strom jeder der mindestens einen unabhängig gesteuerten Heizzone (62) in jeder der Heizungseinheiten (52) durch eine Vielzahl von Stromleitern (56), wobei die Stromleiter (56) elektrisch mit jeder der mindestens einen unabhängig gesteuerten Heizzone (62) in jeder der Heizungseinheiten (52) verbunden ist; und Detektieren einer Temperatur innerhalb jeder der unabhängig gesteuerten Heizzonen (62);
dadurch gekennzeichnet, dass das Verfahren das Modulieren von Strom umfasst, mit dem jede unabhängig gesteuerte Heizzone (62) der Heizungseinheiten (52) durch die Stromleiter (56) basierend auf der detektierten Temperatur innerhalb jeder der unabhängig gesteuerten Heizzonen (62) versorgt wird, um eine gewünschte Wattleistung entlang einer Länge der Heizungsbaugruppe (18) bereitzustellen.
18. Verfahren nach Anspruch 17, weiter umfassend das Vergleichen der detektierten Temperaturen mit Zieltemperaturen und das Modulieren des Stroms, mit dem zum Erreichen der Zieltemperaturen versorgt wird.
19. Verfahren nach Anspruch 17, weiter umfassend das Verwenden eines Skalierungsfaktors zum Anpassen des Modulierungsstroms.
20. Verfahren nach Anspruch 19, weiter umfassend das Verwenden des Skalierungsfaktors in Abhängigkeit von einer Heizkapazität jeder Heizzone (62).
21. Verfahren nach Anspruch 17, weiter umfassend das

- Ausschalten mindestens einer der unabhängig gesteuerten Heizzonen (62) basierend auf der detektierten Temperatur unter fortgesetztem Bereitstellen der gewünschten Wattleistung für die verbleibenden der unabhängig gesteuerten Heizzonen (62). 5
22. Verfahren nach Anspruch 17, wobei, wenn die detektierte Temperatur in mindestens einer der Heizzonen (62) von einer Zieltemperatur abweicht, der Strom für die mindestens eine Heizzone (62) moduliert wird, um die Zieltemperatur zu erreichen. 10
23. Verfahren nach Anspruch 17, wobei das Detektieren der Temperatur das Bestimmen der Temperatur unter Verwendung einer Widerstandsänderung eines Heizwiderstandselements (34) mindestens einer der Heizungseinheiten (52) beinhaltet. 15
24. Verfahren nach Anspruch 23, weiter umfassend das Ausschalten mindestens einer der unabhängig gesteuerten Heizzonen (62) basierend auf der detektierten Temperatur, unter fortgesetztem Bereitstellen der gewünschten Wattleistung für die verbleibenden der unabhängig gesteuerten Heizzonen (62). 20
25. Verfahren nach Anspruch 17, wobei der Strom für jede der Heizzonen (62) in Abhängigkeit von mindestens einem von empfangenen Signalen, einem Modell und in Abhängigkeit von Zeit moduliert wird. 25
26. Verfahren nach Anspruch 17, weiter umfassend das Kalibrieren des Heizungssystems (10) gemäß den folgenden Schritten: 30
- Betreiben des Heizungssystems (10) in mindestens einem Betriebsmodus; 35
- Steuern des Heizungssystems (10) zum Aktivieren mindestens einer der Vielzahl von unabhängig gesteuerten Heizzonen (62), um eine gewünschte Temperatur zu generieren; 40
- Sammeln und Aufzeichnen von Daten für die mindestens eine der unabhängig gesteuerten Heizzonen (62), und den mindestens einen Betriebsmodus; 45
- Zugreifen auf die aufgezeichneten Daten zum Bestimmen von Betriebsspezifizierungen für das Heizungssystem (10), wenn die mindestens eine der Vielzahl von unabhängig gesteuerten Heizzonen (62) ausgeschaltet ist; und 50
- Betreiben des Heizungssystems (10) mit der mindestens einen der Vielzahl von unabhängig gesteuerten Heizzonen (62), die ausgeschaltet ist. 55
27. Verfahren nach Anspruch 26, wobei die Daten aus der Gruppe ausgewählt sind, die aus Strompegeln und Temperaturinformationen besteht.
28. Verfahren nach Anspruch 17, wobei die Vielzahl von Heizungseinheiten (52) entlang einer Längsrichtung der Heizungsbaugruppe (18) disponiert sind, um die Vielzahl von unabhängig gesteuerten Heizzonen (62) entlang der Längsrichtung der Heizungsbaugruppe (18) zu definieren.
29. Verfahren nach Anspruch 17, weiter umfassend das Bereitstellen einer Gesamtheit von $m \times k$ unabhängig gesteuerten Heizzonen (62), wobei die Anzahl der Heizungsbaugruppen (18) k ist, und die Anzahl der unabhängig gesteuerten Heizzonen (62) jeder der Heizungsbaugruppen (18) m ist.
30. Verfahren nach Anspruch 29, weiter umfassend das Ausschalten mindestens einer der unabhängig gesteuerten Heizzonen (62) unter fortgesetzter Stromversorgung der verbleibenden der unabhängig gesteuerten Heizzonen (62), um die gewünschte Wattleistung entlang der Länge der Heizungsbaugruppe (18) bereitzustellen.
31. Verfahren nach Anspruch 17, wobei die Vielzahl unabhängig gesteuerter Heizzonen (62) einzeln und dynamisch gesteuert werden, um eine zuvor bestimmte Stromverteilung durch das Heizungssystem hindurch zu erreichen.
32. Einrichtung zum Heizen einer Flüssigkeit, umfassend: 30
- ein abgedichtetes Gehäuse (72), das eine innere Kammer definiert und einen Flüssigkeitseingang (76) und einen Flüssigkeitsauslass (78) aufweist; und
- das Heizungssystem (10) nach Anspruch 1, das innerhalb der inneren Kammer des Gehäuses (72) disponiert ist, wobei das Heizungsband (12) angepasst ist, um eine zuvor bestimmte Wärmeverteilung für eine Flüssigkeit innerhalb des Gehäuses (72) bereitzustellen.
- Revendications** 45
1. Système de chauffage (10) comprenant un faisceau de chauffage (12), le faisceau de chauffage (12) comprenant : une pluralité d'ensembles de chauffage (18), chaque ensemble de chauffage (18) comprenant une pluralité d'unités de chauffage (52), chaque unité de chauffage (52) définissant au moins une zone de chauffage commandée indépendamment (62) ; une pluralité de conducteurs de puissance (56) reliés électriquement à chacune de l'au moins une zone de chauffage commandée indépendamment (62) dans chacune des unités de chauffage (52) ; et des moyens pour détecter la température

dans chacune des zones de chauffage commandées indépendamment (62) ; et un dispositif d'alimentation électrique (14) ;

caractérisé en ce que le dispositif d'alimentation électrique (14) comporte un dispositif de commande (15) configuré pour moduler la puissance à chacune des zones de chauffage commandées indépendamment (62) des unités de chauffage (52) à travers les conducteurs de puissance (56) sur la base de la température détectée dans chacune des zones de chauffage commandées indépendamment (62) pour fournir une puissance en watts souhaitée sur une longueur de chacun des ensembles de chauffage (18).

2. Système de chauffage (10) selon la revendication 1, comprenant en outre un système de commande automatique en boucle fermée (15) configuré pour commander la puissance provenant du dispositif d'alimentation électrique sur la base des températures détectées dans au moins l'une des zones de chauffage commandées indépendamment (62).
3. Système de chauffage (10) selon la revendication 1, dans lequel les conducteurs de puissance (56) comprennent l'un parmi : une pluralité de conducteurs d'alimentation électrique et de retour de puissance, une pluralité de conducteurs de retour de puissance et un seul conducteur d'alimentation électrique, et une pluralité de conducteurs d'alimentation électrique et un seul conducteur de retour de puissance.
4. Système de chauffage (10) selon la revendication 1, dans lequel les unités de chauffage (52) des ensembles de chauffage (18) ont la même structure de sorte que les unités de chauffage (52) des ensembles de chauffage (18) soient interchangeables.
5. Système de chauffage (10) selon la revendication 1, dans lequel au moins un ensemble d'un conducteur d'alimentation électrique et d'un conducteur de retour de puissance comprend différents matériaux de sorte qu'une jonction soit formée entre les différents matériaux et un élément chauffant résistif (34) d'une unité de chauffage (52) et soit utilisée pour déterminer la température d'une ou de plusieurs des zones de chauffage commandées indépendamment (62).
6. Système de chauffage (10) selon la revendication 1, dans lequel le nombre des zones de chauffage commandées indépendamment (62) est n, et le nombre de conducteurs d'alimentation électrique et de retour de puissance est n+1.
7. Système de chauffage (10) selon la revendication 1, dans lequel chaque ensemble de chauffage (18) définit un axe et la pluralité d'ensembles de chauffage (18) sont agencés de sorte que leurs axes soient

agencés parallèlement les uns aux autres.

8. Système de chauffage (10) selon la revendication 1, dans lequel la pluralité d'unités de chauffage (52) comportent chacune un corps central (32) et un élément chauffant résistif (34) entourant le corps central (32).
9. Système de chauffage (10) selon la revendication 8, dans lequel les conducteurs de puissance (56) s'étendent à travers les corps centraux (32) des unités de chauffage (52).
10. Système de chauffage (10) selon la revendication 9, dans lequel les corps centraux (32) de l'ensemble de chauffage (18) sont reçus dans une gaine métallique (36).
11. Système de chauffage (10) selon la revendication 8, dans lequel le corps central (32) de chaque unité de chauffage (52) définit une pluralité de trous traversants (64).
12. Système de chauffage (10) selon la revendication 11, dans lequel les conducteurs de puissance (56) s'étendent dans la pluralité de trous traversants (64) des corps centraux (32).
13. Système de chauffage (10) selon la revendication 8, dans lequel les corps centraux (32) des unités de chauffage (52) sont réalisés en céramique.
14. Système de chauffage (10) selon la revendication 8, dans lequel les corps centraux (32) de chacun des ensembles de chauffage (18) sont reçus dans une gaine métallique (36).
15. Système de chauffage (10) selon la revendication 14, comprenant en outre un matériau isolant (38) disposé entre les corps centraux (32) et la gaine métallique (36).
16. Système de chauffage (10) selon la revendication 1, dans lequel le nombre des ensembles de chauffage (18) est k, le nombre des zones de chauffage commandées indépendamment (62) de chacun des ensembles de chauffage (18) est m, et un nombre total des zones de chauffage commandées indépendamment (62) définies par le faisceau de chauffage (12) est m x k.
17. Procédé de commande d'un système de chauffage (10) comprenant le fait : de fournir une pluralité d'ensembles de chauffage (18), l'ensemble de chauffage (18) comprenant une pluralité d'unités de chauffage (52), chaque unité de chauffage (52) définissant au moins un zone de chauffage commandée indépendamment (62) ; de fournir une puissance à chacune

- de l'au moins une zone de chauffage commandée indépendamment (62) dans chacune des unités de chauffage (52) à travers une pluralité de conducteurs de puissance (56), les conducteurs de puissance (56) étant reliés électriquement à chacune de l'au moins une zone de chauffage commandée indépendamment (62) dans chacune des unités de chauffage (52) ; et de détecter une température dans chacune des zones de chauffage commandées indépendamment (62) ;
- caractérisé en ce que** le procédé comprend le fait de moduler la puissance fournie à chacune des zones de chauffage commandées indépendamment (62) des unités de chauffage (52) à travers les conducteurs de puissance (56) sur la base de la température détectée dans chacune des zones de chauffage commandées indépendamment (62) pour fournir une puissance en watts souhaitée sur une longueur de l'ensemble de chauffage (18).
18. Procédé selon la revendication 17, comprenant en outre le fait de comparer les températures détectées à des températures cibles et de moduler la puissance fournie pour atteindre les températures cibles.
 19. Procédé selon la revendication 17, comprenant en outre le fait d'utiliser un facteur d'échelle pour ajuster la puissance de modulation.
 20. Procédé selon la revendication 19, comprenant en outre le fait d'utiliser le facteur d'échelle en fonction d'une capacité de chauffage de chaque zone de chauffage (62).
 21. Procédé selon la revendication 17, comprenant en outre le fait de désactiver au moins l'une des zones de chauffage commandées indépendamment (62) sur la base de la température détectée tout en continuant à fournir la puissance en watts souhaitée aux zones restantes des zones de chauffage commandées indépendamment (62).
 22. Procédé selon la revendication 17, dans lequel lorsque la température détectée dans au moins l'une des zones de chauffage (62) est déviée d'une température cible, la puissance est modulée à l'au moins une zone de chauffage (62) pour atteindre la température cible.
 23. Procédé selon la revendication 17, dans lequel la détection de la température comporte la détermination de la température en utilisant un changement de résistance d'un élément chauffant résistif (34) d'au moins l'une des unités de chauffage (52).
 24. Procédé selon la revendication 23, comprenant en outre le fait de désactiver au moins l'une des zones de chauffage commandées indépendamment (62) sur la base de la température détectée, tout en continuant à fournir la puissance en watts souhaitée aux zones restantes des zones de chauffage commandées indépendamment (62).
 25. Procédé selon la revendication 17, dans lequel la puissance est modulée à chacune des zones de chauffage (62) en fonction d'au moins l'un des signaux reçus, d'un modèle, et en fonction du temps.
 26. Procédé selon la revendication 17, comprenant en outre le fait d'étalonner le système de chauffage (10) selon les étapes suivantes qui consistent :
 - à faire fonctionner le système de chauffage (10) dans au moins un mode de fonctionnement ;
 - à commander le système de chauffage (10) pour activer au moins l'une de la pluralité de zones de chauffage commandées indépendamment (62) pour générer une température souhaitée ;
 - à collecter et à enregistrer des données pour l'au moins une des zones de chauffage commandées indépendamment (62) et l'au moins un mode de fonctionnement ;
 - à accéder aux données enregistrées pour déterminer les spécifications de fonctionnement pour le système de chauffage (10) lorsque l'au moins une de la pluralité de zones de chauffage commandées indépendamment (62) est désactivée ; et
 - à faire fonctionner le système de chauffage (10) avec l'au moins une de la pluralité de zones de chauffage commandées indépendamment (62) désactivée.
 27. Procédé selon la revendication 26, dans lequel les données sont choisies dans le groupe constitué d'informations de température et de niveaux de puissance.
 28. Procédé selon la revendication 17, dans lequel la pluralité d'unités de chauffage (52) sont disposées le long d'une direction longitudinale de l'ensemble de chauffage (18) pour définir la pluralité de zones de chauffage commandées indépendamment (62) le long de la direction longitudinale de l'ensemble de chauffage (18).
 29. Procédé selon la revendication 17, comprenant en outre le fait de fournir un total de $m \times k$ zones de chauffage commandées indépendamment (62), où le nombre des ensembles de chauffage (18) est k , et le nombre des zones de chauffage commandées indépendamment (62) de chacun des ensembles de chauffage (18) est m .
 30. Procédé selon la revendication 29, comprenant en outre le fait de désactiver au moins l'une des zones

de chauffage commandées indépendamment (62) tout en continuant à fournir une puissance aux zones restantes des zones de chauffage commandées indépendamment (62) pour fournir la puissance en watts souhaitée sur la longueur de l'ensemble de chauffage (18). 5

31. Procédé selon la revendication 17, dans lequel la pluralité de zones de chauffage commandées indépendamment (62) sont commandées individuellement et dynamiquement pour obtenir une distribution de puissance prédéterminée à travers le système de chauffage. 10

32. Appareil pour chauffer un fluide comprenant : 15

un boîtier scellé (72) définissant une chambre interne et ayant une entrée de fluide (76) et une sortie de fluide (78) ; et
le système de chauffage (10) selon la revendication 1 disposé dans la chambre interne du boîtier (72),
dans lequel le faisceau de chauffage (12) est adapté pour fournir une distribution de chaleur prédéterminée à un fluide dans le boîtier (72). 20 25

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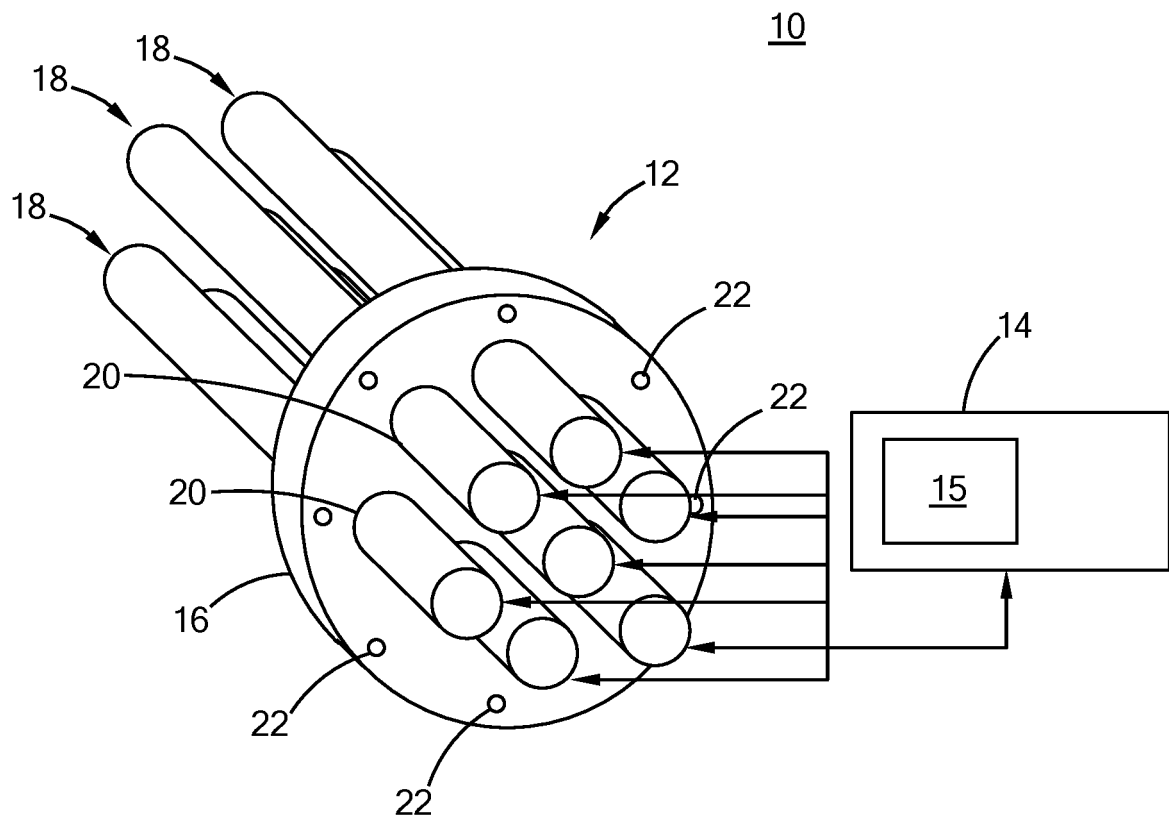


FIG. 1

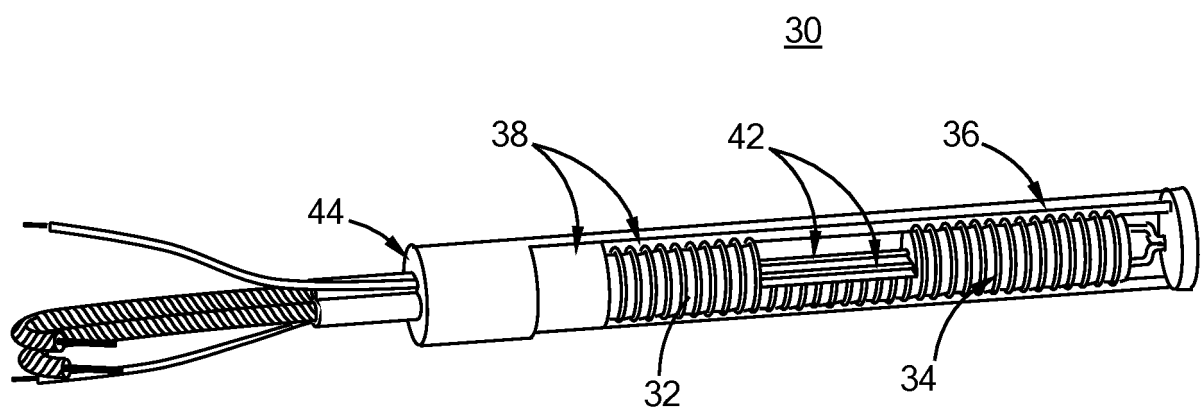
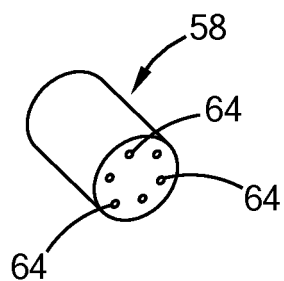
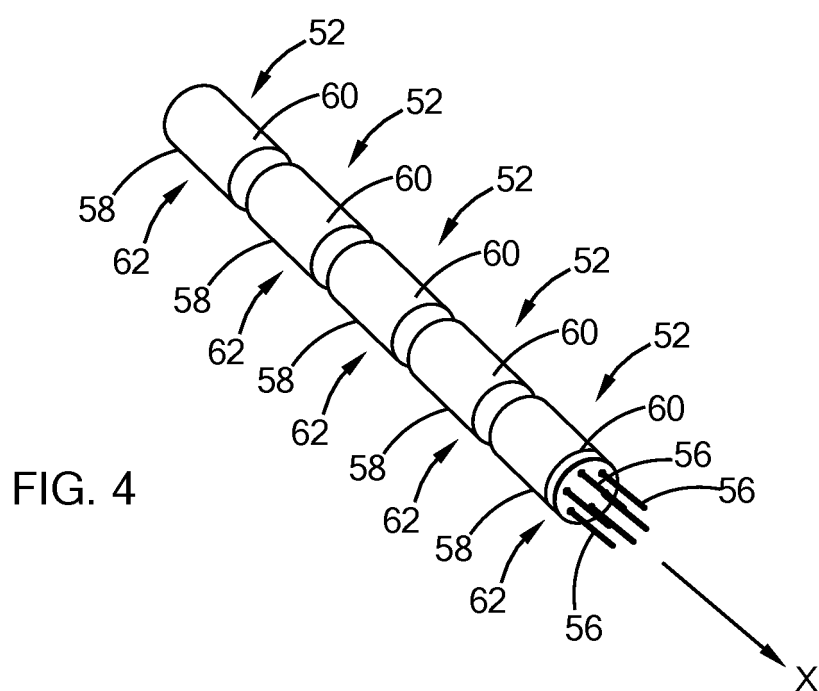
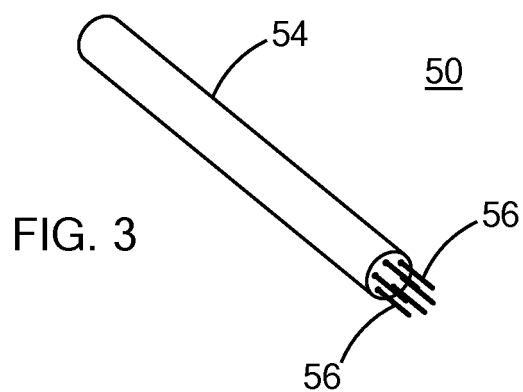


FIG. 2



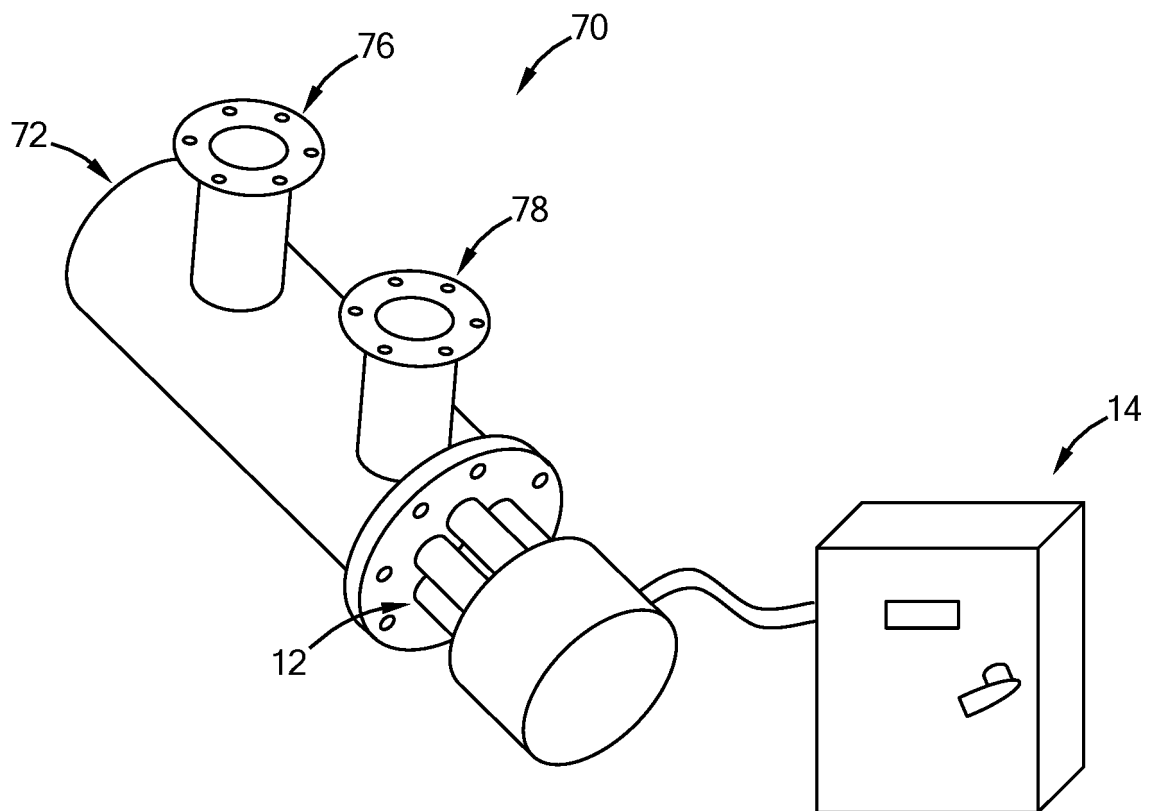


FIG. 6

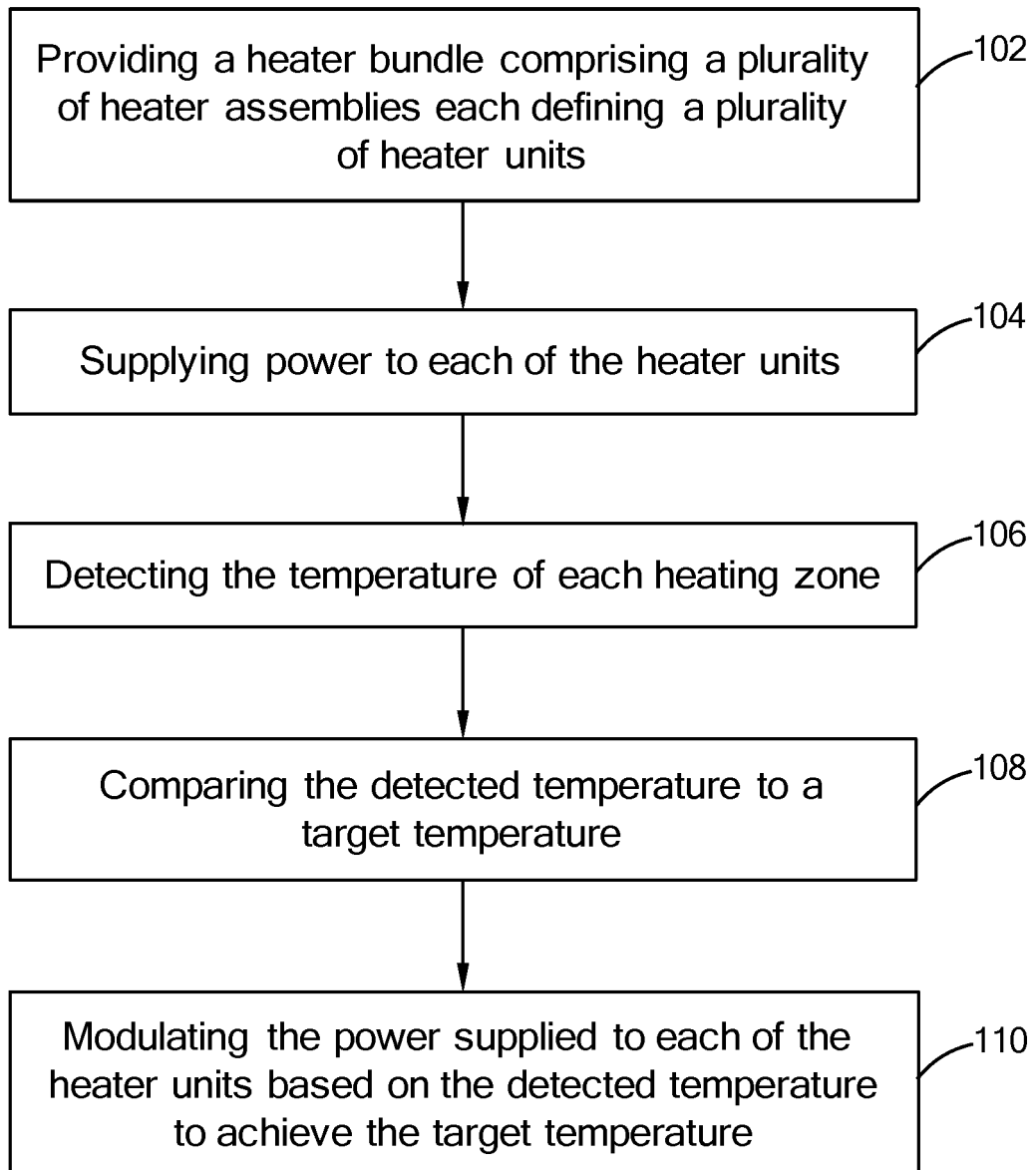
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FIG. 7

REFERENCES CITED IN THE DESCRIPTION

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